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Relationship between forest canopy and natural regeneration in the subalpine spruce-larch forest (north-east Italy)

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Abstract

The authors describe the difference between canopy cover (proportion of the forest floor covered by the vertical projection of the tree crowns) and canopy closure (proportion of sky hemisphere obscured by vegetation when viewed from a single point) and the respective ground-based estimation techniques focused on two types of densiometer (GRS tube and spherical). The data collected in the field were used to analyse the relationship between forest canopy and natural regeneration in two subtypes of subalpine larch-spruce forests. The results indicate that in the first subtype characterized by a high fertility and a high canopy cover (around 62%), the level of natural regeneration is low (115 stems per hectare) and it is nearly exclusively composed by spruce [*Picea abies* (L.) Karst.]. For the second subtype characterized by a low fertility and a medium canopy cover (around 49%) the natural regeneration is rather dense (650 stems per hectare). At last the authors evidence a insignificant difference between the data of forest canopy collected by different ground-based estimation techniques (+0.7% using spherical densiometer compared to using GRS tube densiometer).

Key words

canopy closure, canopy cover, GRS tube densiometer, natural regeneration, spherical densiometer

Introduction

Forest canopy cover, also known as canopy coverage or crown cover (Gill *et al.* 2000), is a fundamental parameter used in the forest inventories to distinguish forest from other land uses (Falkowski *et al.* 2008).

Canopy cover is defined as the proportion of the forest floor covered by the vertical projection of the tree crowns (Avery and Burkart 1994). In literature, some authors distinguish this concept from canopy closure in consideration of the different ecological meaning. Canopy closure is the proportion of sky hemisphere obscured by vegetation when viewed from a single point (Jennings *et al.* 1999) and, with the maximum expansion's degree of its angle of view, it's a projection of a hemisphere onto a plane (Daubenmire 1959). In other words, according to Korhonen *et al.* (2006) canopy cover describes the fraction of ground area covered by crowns

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(Fig. 1), while canopy closure describes the fraction of non-visible sky within a certan angle (Fig. 2).

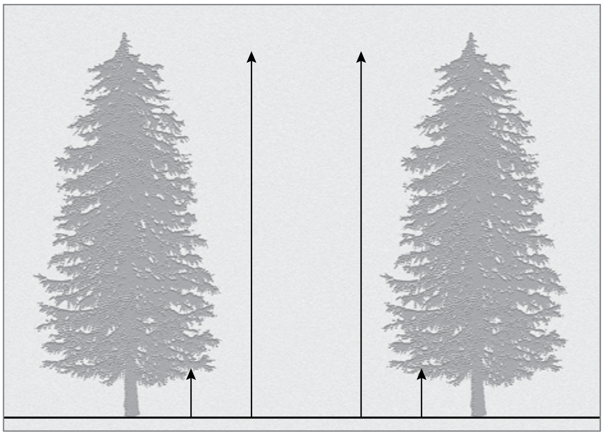

Fig. 1. Canopy cover is measured in vertical direction

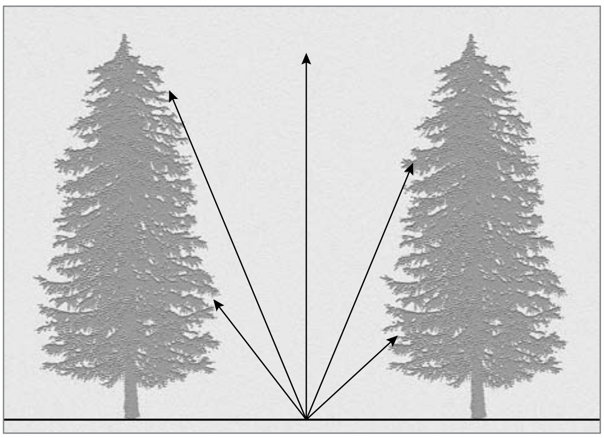

Fig. 2. Canopy closure is measured with instruments that have an angle of view

Canopy cover influences numerous ecological processes in forest communities (Cook *et al.* 1995) and it is a significant variable in studies of natural hazards dynamics (landslides, rockfalls, snow slippage and avalanches) (Berger and Rey 2004), in forest protective function assessment models (Bebi *et al.* 2001), understory vegetative productivity (McConnell and Smith 1970) and in forest management and planning (Fiala *et al.* 2006). Moreover, canopy cover is useful for estimating functional variables like the leaf area index (LAI), which are key information for understanding biological and physical processes associated with vegetation (Colombo *et al.* 2003).

Canopy closure affects plant growth and survival, hence determining the nature of the vegetation. It is an important ecological parameter of forest ecosystem for its relationship with species richness, wildlife habitat and natural regeneration (Ganey and Block 1994; Zollner and Crane 2003). In particular the canopy closure increased with species richness but also varied significantly between pure stands of different species (DeClerck *et al.* 2005).

The quantitative estimation of canopy cover and canopy closure is useful to estimate penetration of light to the understory (Englund *et al.* 2000) and to classify stand structure (Lieffers *et al.* 1999). Although this acknowledged importance, there is no standard measurement method to estimate forest canopy in quantitative terms (Fiala *et al.* 2006; Chincarini *et al.* 2009). Commonly used ground-based methods comprise sophisticated techniques such as hemispherical photography (Newton 2007) and speedy techniques such as moosehorn (Garrison 1949), convex and concave spherical densiometer (Lemmon 1956), vertical tube (Johansson 1985) and visual estimates (Braun-Blanquet 1928).

The aim of this study was to investigate the relationship between forest canopy and natural regeneration in mixed stands of larch (*Larix decidua* Mill.) and spurce [*Picea abies* (L.) Karst.]. Furthermore, we have compared the difference between canopy cover and canopy closure using two different ground-based estimation techniques (spherical and GRS tube densiometer) with the purpose to determine which variable is better correlate with regeneration composition and density.

Material and methods

This study was conducted in the Mocheni valley (latitude 46° 08′ N, longitude 11° 30′ E), which lies 20 km northeast of the city of Trento in Trentino-Alto Adige region (North-east Italy). The study area is located at an elevation of around 1.500 m above sea level. In Mocheni valley (Sant'Orsola meteo station) the climate is cool, temperate and mild continental. The annual average is 3.63°C, with a mean annual maximum temperature of 16.9°C and a mean annual minimum temperature of –12.8°C. The annual rainfall averages is 911 mm with two main peak periods, in spring (June rainfall averages 110 mm) and in autumn (October rainfall averages 100 mm).

According to the European classification of forest types (EEA 2006), the area of study is a subalpine coniferous forest, partly dominated by larch (*L. decidua*) with admixture of spruce (*P. abies*). Subalpine larch-spruce forests are open forests with a dense shrub layer consisting of *Rhododendron ferrugineum* L., *Rhododendron hirsutum* L., *Sorbus aucuparia* L., *Vaccinium myrtillus* L. and *Juniperus communis* L.. The two subtypes of larch-spruce forest are characterised by a different soil fertility: the first subtype (A) has a low fertility and the larch is in its ecological optimum, while the second subtype (B) has a higher fertility and it is a subalpine larch forest in transition towards a spruce forest. The data of natural regeneration and canopy cover (closure) were collected during the summer (from June to August) 2008 in 30 plots located in two different subtypes of forest. On the whole 16 plots (plot code: 1–16) are located in the subtype A and 14 plots (plot code numer: 17–30) in the subtype B. The distance between plots was 500 m and thus the total forest area investigated was around 40 hectares.

The plot is a circular area with a radius of 13 m on a topographic plane for a total surface of 531 m^2. The main stand inventory parameters measured were: forest subtypes, number of trees, diameter at breast height (DBH), tree height of the five trees nearest to the plot centre according to the second Italian National Inventory of Forests and Forest Carbon Sinks (INFC). These dendrometric measures were used to calculate the stem basal area, the quadratic mean diameter, the average height and stand density. Moreover, in each plot we have measured: the number of regeneration stems (stems with a height less than 130 cm and stems higher to 130 cm but with a DBH less than 4.5 cm), the canopy cover using the GRS tube densiometer and the canopy closure using the spherical densiometer.

In each plot, we have numbered all seedlings and saplings and recorded: species, height, size classes and possible damage (biotic and abiotic). The seedlings and saplings are divided by four height size classes: stems with $h \leq 10$ cm, stems with $10.5 < h \leq 50$ cm, stems with $50.5 < h \leq 130$ cm, stems with $h > 130$ cm and DBH < 4.5 cm. The damage at the regeneration stems are classified considering the type of damage (Notaro *et al.* 2009): fire, domestic and wildlife grazing, insect pest, fungi.

The spherical densiometer (Fig. 3) consists of a convex mirror etched with a grid of 24 squares (1/4''), each of them is then equally subdivided into 4 smaller squares (1/8'' × 1/8''). The mirror is mounted in wooden boxes (3 cm × 3 cm × 1 cm) with hinged lids and a circular spirit level is mounted beside the mirror. The cross-shaped grid with squares and dots are used to estimate overstory coverage by tree crowns. The observer can then count the number of dots up to a total of 96 (24 squares subdivided into 4 smaller squares), the number determined is then multiplied by 1.04 to obtain the percent of overhead area not occupied by canopy (canopy openness) (Lemmon 1956). The angle of view of spherical densiometer using the total dots is equal to 60° (Korhonen *et al.* 2006). In our study case, for each plots we have previewed only one survey point in the centre of plots and four measure with the operator's angle of view in direction of North, South, East and West. The accuracy and precision of the spherical densiometer to estimate forest canopy is questionable (Griffing 1985; Ganey and Block 1994), but it is a quick and easy method useful in the elaboration of forest management plan (Paletto and Tosi 2009).

Fig. 3. Spherical densiometer

For each plot we have previewed one survey point localized in the plot centre where the operator has conducted four measures with convex spherical densiometer mounted on a tripod oriented in direction of a different cardinal point. The canopy closure is the average of the four cardinal point measures.

The GRS tube densiometer (Fig. 4) is a tube made of PVC pipe with a crosshair fashioned out of baling wire.

It is constituted by a vertical tube of brass mounted on a universal joint to make it hang vertically during the measurement operation. The observer looked directly overhead through the tube, so that the hair cross can be seen in the mirror, and recorded whether the area of reflected cross is crown covered or is open sky (Johansson 1985).

Fig. 4. GRS tube densiometer

In each plot the operator has measured with GRS tube densiometer 45 points (Fig. 5) recording for each individual measurement "1" if the view is obstructed and "0" otherwise. The canopy cover is estimated as the mean of these binomial (Bernulli) variables (Korhonen *et al.* 2006).

The difference of forest canopy measured by spherical densiometer and GRS tube densiometer were compared using the non-parametric test of Wilcoxon. The statistical test of Wilcoxon compares two paired groups and it calculates the difference between each set of pairs, and analyzes that list of differences. It is used to test the null hypothesis (H_0) that two samples come from identical populations against the alternative hypothesis (H_1) that the two samples come from different populations.

The relationship between forest canopy and regeneration of trees was tested using the Kendall's rank cor-

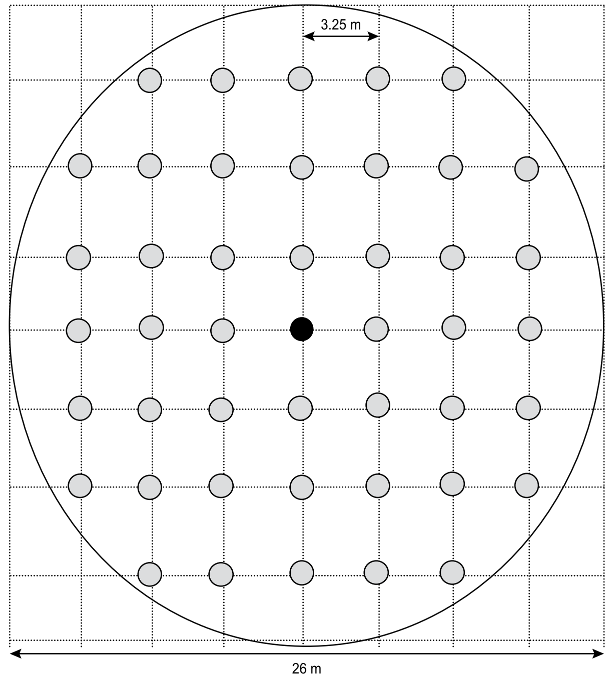

Fig. 5. Plot design with spherical densiometer (in black) and GRS tube densiometer (in black and grey) measurement points

relation coefficient (τ). Kendall's correlation measures the extent to which, as one variable increases, the other variable tends to increase, without requiring that increase to be represented by a linear relationship. In particular we have tested the relationship between forest canopy and the number of larch and spruce seedlings and saplings. The results of canopy cover and canopy closure are compared to determine which variable is better correlate with the regeneration composition and density.

We have used the non-parametric methods (Wilcoxon test and Kendall's rank correlation coefficient) because the distributions do not fit normal distributions.

Results

In Table 1, the quantitative dendrometric characteristics of each plot (basal area, quadratic mean diameter, average height and stand density) were given to characterize the structure of the stands by subtype. The subtype A is dense (basal area = 45.1 m^2/ha) with medium size tree

Tab. 1. Dendrometric characteristics and forest canopy measured by spherical and GRS densiometer

Plot no.	Subtype community	Basal area (m^2/ha)	Quadratic mean diameter (cm)	Stand density (stems/ha)	Average height (m)	Spherical densiometer (%)	Densiometer GRS (%)
1	A	70.8	40.6	547	13.3	46.28	57.7
2	A	54.0	42.7	377	24.3	74.88	64.4
3	A	37.3	35.5	377	21.3	56.68	55.5
4	A	33.1	26.8	585	20.0	66.04	46.6
5	A	33.1	30.5	453	22.7	65.78	55.5
6	A	70.5	39.8	566	28.0	92.04	68.8
7	A	37.1	33.0	434	18.0	80.34	66.6
8	A	33.3	28.3	528	24.7	74.10	66.6
9	A	29.6	28.9	453	19.3	68.90	64.4
10	A	61.6	35.5	623	31.0	54.60	57.7
11	A	51.9	33.6	585	24.7	58.76	66.6
12	A	35.7	35.6	359	23.3	63.70	60.0
13	A	31.4	33.4	359	27.7	44.20	48.8
14	A	58.7	32.7	698	25.3	57.72	68.8
15	A	41.7	34.2	453	27.0	54.08	62.2
16	A	42.4	38.8	359	21.0	48.88	53.3
17	B	54.6	51.3	264	31.3	58.75	62.2
18	B	47.4	28.6	736	28.3	58.50	77.7
19	B	41.0	35.5	415	27.0	47.58	55.5
20	B	35.7	37.6	321	17.3	46.54	42.2
21	B	45.9	45.5	283	23.3	41.60	60.0
22	B	15.0	18.1	585	19.3	57.46	64.4
23	B	13.5	33.8	151	17.7	36.14	24.4
24	B	27.4	45.3	170	28.0	34.58	26.6
25	B	42.1	43.5	283	19.7	51.22	46.6
26	B	24.6	35.7	245	31.7	46.80	46.6
27	B	22.5	41.1	170	25.3	48.88	48.8
28	B	35.8	40.1	283	24.3	44.72	48.8
29	B	41.7	39.5	340	23.7	59.28	51.1
30	B	29.8	40.9	226	21.3	38.48	37.7
Mean	A + B	40.0	36.2	408	23.7	55.90	55.2
Std.Dev.	A + B	14.2	6.6	158	4.5	13.10	12.2
Mean	A	45.1	34.4	485	23.2	63.90	60.7
Std. Dev.	A	14.1	4.5	108	4.4	12.90	7.0
Mean	B	34.1	38.3	319	24.2	48.00	49.7
Std. Dev.	B	12.4	8.1	164	4.7	8.10	13.9

Tab. 2. Regeneration (seeding and sapling) density by species* and size class

Plot no.	h ≤ 10 cm	10.5 < h ≤ 50 cm	50.5 < h ≤ 130 cm	h > 130 cm	Total	Damage (%)
1	*14*/**0**	*7*/**1**	*2*/**0**	*1*/**0**	*24*/**1**	14
2	*3*/**0**	*2*/**0**	*1*/**0**	*4*/**0**	*10*/**0**	0
3	*8*/**4**	*2*/**0**	*2*/**0**	*3*/**0**	*15*/**4**	5
4	*0*/**0**	*4*/**1**	*5*/**0**	*7*/**0**	*16*/**1**	17
5	*0*/**0**	*3*/**3**	*9*/**3**	*1*/**0**	*13*/**6**	8
6	*0*/**0**	*1*/**0**	*0*/**0**	*3*/**0**	*4*/**0**	10
7	*0*/**0**	*1*/**0**	*0*/**0**	*5*/**0**	*6*/**0**	0
8	*0*/**0**	*1*/**0**	*3*/**0**	*5*/**0**	*9*/**0**	3
9	*1*/**0**	*2*/**1**	*2*/**0**	*2*/**0**	*7*/**1**	0
10	*0*/**0**	*0*/**0**	*3*/**0**	*5*/**0**	*8*/**0**	25
11	*0*/**0**	*1*/**2**	*4*/**0**	*6*/**0**	*11*/**2**	5
12	*0*/**0**	*0*/**0**	*0*/**2**	*1*/**0**	*1*/**2**	7
13	*0*/**0**	*3*/**0**	*0*/**0**	*4*/**0**	*7*/**0**	0
14	*0*/**0**	*3*/**0**	*0*/**0**	*2*/**0**	*5*/**0**	20
15	*0*/**0**	*2*/**0**	*5*/**0**	*3*/**0**	*10*/**0**	8
16	*1*/**14**	*3*/**1**	*7*/**0**	*6*/**0**	*17*/**15**	25
17	*88*/**40**	*12*/**0**	*8*/**0**	*1*/**0**	*109*/**40**	3
18	*23*/**6**	*14*/**0**	*6*/**0**	*3*/**0**	*46*/**6**	6
19	*20*/**27**	*10*/**0**	*5*/**0**	*2*/**0**	*37*/**27**	8
20	*70*/**56**	*2*/**1**	*4*/**0**	*5*/**0**	*81*/**57**	3
21	*30*/**165**	*8*/**0**	*7*/**0**	*0*/**0**	*45*/**165**	3
22	*10*/**0**	*2*/**0**	*6*/**0**	*17*/**0**	*35*/**0**	3
23	*0*/**0**	*7*/**6**	*7*/**1**	*7*/**0**	*21*/**7**	7
24	*3*/**30**	*9*/**1**	*9*/**0**	*5*/**0**	*26*/**31**	19
25	*0*/**13**	*3*/**0**	*6*/**0**	*2*/**0**	*11*/**13**	34
26	*5*/**12**	*7*/**2**	*6*/**0**	*2*/**0**	*20*/**14**	18
27	*1*/**28**	*3*/**0**	*5*/**0**	*6*/**0**	*15*/**28**	16
28	*0*/**18**	*7*/**0**	*23*/**0**	*6*/**0**	*36*/**18**	22
29	*0*/**18**	*10*/**0**	*18*/**0**	*3*/**0**	*31*/**18**	28
30	*3*/**11**	*5*/**2**	*5*/**0**	*3*/**0**	*16*/**13**	18
Mean (larch)	14.73	0.70	0.20	0.00	15.63	–
Std. Dev. (larch)	31.75	1.29	0.66	0.00	31.52	–
Mean (spruce)	9.33	4.47	5.27	4.00	23.07	–
Std. Dev. (spruce)	20.57	3.74	5.00	3.14	23.30	–
Mean (larch + spruce)	24.06	5.17	5.47	4.00	38.70	11.16
Std. dev. (larch + spruce)	45.45	4.04	5.06	3.14	47.58	9.46

* Spruce (*in italic type*), Larch (**in bold type**)

(quadratic mean diameter = 34.4 cm), while the subtype B has few large trees (basal area mean = 34.1 m^2/ha, quadratic mean diameter = 38.3 cm).

The results of forest canopy measured with the spherical densiometer and GRS densiometer didn't show a significant differences (Tab.1 and Fig.6). The total results (30 plots) measured with spherical densiometer (55.9%) are a little-bit higher in comparison with the GRS densiometer results (55.2%) but the application of nonparametric Wilcoxon test does not a highlight significant difference (V = 256; p-value = 0.641). These results are different from other research that considers the spherical densiometer more apt to measure the canopy closure and the vertical densiometer more apt to measure the canopy cover (Korhonen *et al.* 2006; Paletto and Tosi 2009). In this research the authors evidence a difference between spherical and GRS densiometer of +0.7%, while Paletto and Tosi (2009) have found a difference in four forest categories analysed (spruce, fir, beech and larch stands) of +13.2% and a specific difference for the larch stands of +15.2%.

The analysis of results has revealed low difference linked to the instrument: for the subtype A the spherical densiometer has measured an average forest canopy of 63.87% and the GRS densiometer of 60.68% (mean difference = +3.19%), while for the subtype B the spherical densiometer has pointed out a forest canopy of 47.96% and the GRS densiometer of 49.73% (mean difference = –1.77%). Consequently the difference are linked to the forest subtypes and not necessarily to the instrument used: the first subtype has a medium forest cover around 60% and the second subtype has a medium-low forest cover (48%).

In Table 2 the results of regeneration, on average each plot have a comparable number of subject of larch (mean = 294 stems per hectare) and spruce (mean = 434 stems per hectare). First class of regeneration is larger compared to the other (mean larch = 277 larch stems per hectare; mean = 176 spruce stems per hectare), however the larch regeneration is concentrated in the first class (h < 10 cm), while for the spruce the distribution is more even.

The relationship between forest canopy cover and regeneration depends on two main key-variables: species ecology and dynamics of forest canopy in time and space. Kendall's rank correlation coefficient evidences that both spruce ($\tau = -0.368$; p-value = 0.004) and larch ($\tau = -0.407$; p-value = 0.002) regeneration have a negative linear relationship with canopy closure (Fig. 7 and 8). The same results are confirmed considering the relationship between spruce ($\tau = -0.267$; p-value = 0.038) and larch ($\tau = -0.398$; p-value = 0.002) regeneration and can-

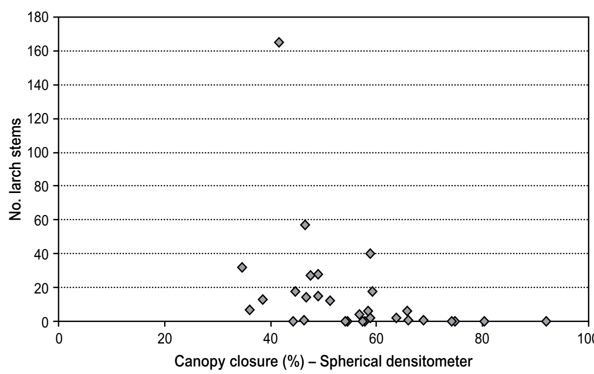

Fig. 7. Relationship between canopy closure and larch regeneration density

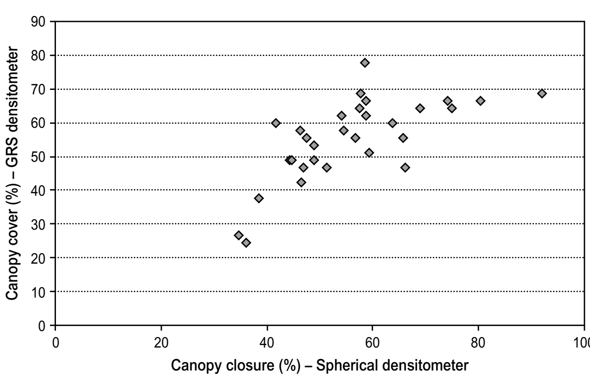

Fig. 6. Relationship between canopy closure and canopy cover

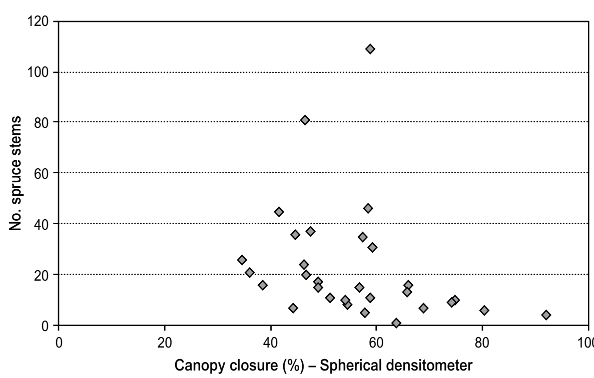

Fig. 8. Relationship between canopy closure and spruce regeneration density

opy cover measured with GRS densiometer (Fig. 9 and 10). When canopy cover increases, the amount of shade-tolerant (spruce) regeneration will moderately decrease, while the amount of shade-intolerant species (larch) will greatly decrease. Using the canopy closure alternatively to the canopy cover the trends are confirmed.

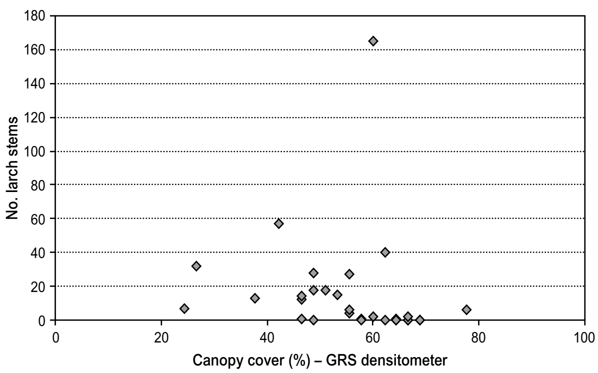

Fig. 9. Relationship between canopy cover and larch regeneration density

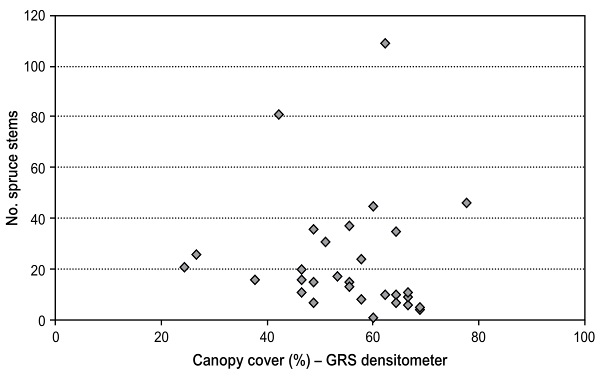

Fig. 10. Relationship between canopy cover and spruce regeneration density

In the forest subtype A, characterized by a more closed canopy (62.3%) the regeneration is very low (mean = 115 spruce and larch stems per hectare) and it is nearly exclusively composed by spruce. In the forest subtype B, where the crown canopy is medium-low (48.8%), the number of young stems is higher (mean = 650 spruce and larch stems per hectare). In consideration of dynamics of forest canopy to improve the larch regeneration, in particular in the subtype B, is necessary to open gaps in the forest.

In consideration of regeneration damage the results evidence that only the 11.2% of total stems are damaged. In particular the first cause of damage is the grazing localized in the subtype B (plots from 24 to 30).

Discussion and conclusions

The relevant aspects discussed in this paper are the measurement difference between canopy closure and canopy cover and the influence of these parameters upon the natural regeneration. In particular, selection of a ground-based method for measuring forest canopy depends on study objectives: sophisticated techniques (i.e. hemispherical photography) are adapted to scientific researches, while fast techinques (i.e. ocular estimates and densiometers) are adapted in the forest planning. Densiometers may have low accuracy and low precision in the estimation of forest canopy (Ganey and Block 1994), but it is a quick and easy method useful in the standardized measurement campaign. Spherical densiometer is apt to estimate the canopy closure because using the total squares (24 squares) the angle of view is equal to 60°, while GRS tube densiometer is more apt to measure the canopy cover because it measure vertical projection of the tree crowns. The time employed in order to estimate the forest canopy per plot is minimum using the spherical densiometer (8–10 minutes) and maximum using the GRS tube densiometer (15–20 minutes).

The study of relationship between forest canopy and regeneration is a key-information to improve the forest planning and management. In this situation it is necessary to collect many data in a short time, therefore the use of spherical densiometer with a reduced angle is particularly useful. According to Korhonen et al. (2006), the observer localized in the center of plot use only four squares out and the original angle of view (60°) could be reduced to about 20°. This methodological trick allows to use the spherical densiometer also for the estimation of canopy cover.

Light conditions play a key role in gap-phase regeneration of forests (Dai X. 1996), according to Canham *et al.* (1994) and Kobe *et al.* (1995) the regenetation of woody plants is linked to the forest canopy gaps. Canopy gaps influence some parameters of microclimate like light intensity, air temperature and air humidity (Dobrowolska 2006) and its encourage the establishment and growth of new species (Duncan 2002). Natural (mortality) and artificial (harvest) disturbances can create forest canopy gaps that change the competitive interactions by making light, moisture, nutrients and space available to survivors (Rhoads *et al.* 2004).

The results of this study demonstrate that the regeneration density has a negative linear relationship with forest canopy in consideration of species ecology and forest composition. Shade-tolerant species (i.e. spruce) need of a high forest canopy, while shade-intolerant species (i.e. larch) prefer a low or medium forest canopy.

Finally, another important information to understand the probability of seedling survival and the mortality causes is the regeneration damage (Maresi and Salvadori 2004). The mortality causes can be directly or indirectly linked to the light conditions.

In conclusion is necessary that forest inventories and forest management plans include systematically the measure of forest canopy using the most appropriate ground-based estimation technique in consideration of the specific objectives.

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